General Electric Advanced Technology Manual

Chapter 6.6

Rod Control Systems

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6.6 ROD CONTROL SYSTEMS

Learning Objectives:

1. State the purpose(s) of the Reactor Manual Control System, Rod Worth Minimizer, Rod Sequence Control System, Rod Block Monitoring System, and Rod Control and Information System.

2. Explain how control rod motion is achieved with the Reactor Manual Control System and Rod Control and Information System.

3. State the major advantages the Rod Control and Information System has over the Reactor Manual Control System.

4. List the types of rod blocks and when they are in effect for the Rod Worth Minimizer, Rod Sequence Control System, and the Rod Block Monitoring System.

6.6.1 Introduction

The Rod Control System for BWR/2 through BWR/5 product lines utilize a collection of systems to accomplish the same purpose as the Rod Control and Information System supplied with the BWR/6 product line. The collection of systems used include the Reactor Manual Control System, Rod Worth Minimizer System, Rod Sequence Control System, and the Rod Block Monitoring System. The purposes of the Rod Control Systems are:

- Provide a means of changing core reactivity to change reactor power level and control flux distribution.

- Enforce rod patterns to limit rod worth and reduce the effects from rod drop accident or rod withdraw error.

6.6.2 BWR/2 Product Line

The BWR/2 product lines control rod worth and provide a means of changing core reactivity with the Reactor Manual Control System and the Rod Worth Minimizer System. Discussion of these systems is found in the paragraphs that follow.

6.6.2.1 Reactor Manual Control System

The Reactor Manual Control System (Figure 6.6-1) consists of the switches, relays, interlocks, alarms, and electrical equipment necessary to result in control rod movement. The RMCS provides the necessary sequence and timing signals to the directional control solenoid valves of the control rod selected for movement. Normal control rod movement is one notch at a time through the timing sequence, but continuous movement controls are provided. The basic inputs to the RMCS are manual via the rod select pushbuttons and rod movement control switches. Interlocks are provided to block the selection and/or movement of a control rod if plant conditions are abnormal. The major components of the Reactor Manual Control System are discussed in the paragraphs that follow.

Rod Select Matrix

The manual rod selection capability is provided by pushbutton type switches, one for each rod, arranged to the approximate geometry of the core. The pushbuttons are wired so that when one switch is depressed, control power is removed from all other rod select pushbuttons.

Rod Selection Relays

Energization of the rod selection relay indicates that the rod select pushbutton request has been honored and the control rod is allowed to be selected for movement. For the selection to be honored, select block interlocks must be satisfied.

Rod Control Relays

The rod control relays allow the request for rod movement to be transmitted from the rod movement control switches to the timer logic, if certain permissives are met. These permissives are termed “rod blocks” and either insert or withdraw blocks.

Timer Logic

The timer logic provides the required signals to the directional control solenoid valves in the proper sequence and timing to cause the selected rod drive to respond as requested by the operator.

Rod Movement Control Switches

Control rod drive movement request is accomplished through the use of two control switches, the control rod movement control switch and/or emergency in notch override switch.

The control rod movement control switch is a three position switch: rod in, off and rod out notch (spring return to off). Through the use of this switch, the operator can initiate notch in and notch out cycles. Notch movement means moving a control rod from one even position indication to the next. If the switch is held in the rod in position, the control rod will continuously drive in until released.

The emergency in notch override switch allows the operator to make a continuous rod withdrawal when used simultaneously with the rod movement control switch. The emergency in position is provided to allow control rod selection if the timer logic is not available or wanted.

6.6.2.2 Rod Worth Minimizer

The Rod Worth Minimizer (RWM), Figure 6.6-2, serves as a backup to procedural controls to limit rod worth during low power operation so that the postulated rod drop accident will not exceed the allowed limit of 280 calories/gram. Table 6.6-1 provides additional information for other cal/gm values.

Rod movement sequences are developed to limit rod worth to a level below which, if a rod drop accident were to occur at a free fall rate limited by the velocity limiter, the enthalpy from the transient would be less than 280 calories/gram. Figure 6.6-3 shows rod worth curves relative to the danger level for unrestrained rod movement (curve A) and RWM restrained movement (curve B). Due to lower rod worth at power, the RWM is not needed to limit rod worth above 20% power. The major components or the RWM are the computer program and the operator’s display panel.

Operating Sequence

The Rod Worth Minimizer program contains an operating sequence which is loaded into computer memory. The operating sequence is a schedule to be followed by the plant operator when withdrawing or inserting control rods. The sequence identifies the control rod XX-YY coordinates and the positions to which each rod should be withdrawn in going from shutdown to full power. When going down in power, the rods are inserted in the reverse order of their withdrawal. The operating sequence is sequentially subdivided into rod groups.

Each rod group consists of a number of specified control rods and a set of insert and withdraw position limits that apply to each rod in the group. The groups are numbered in the order in which they are to be withdrawn when going up in power. Each sequence generally begins by withdrawing approximately half of the rods in the core to full out. Under cold conditions, this brings the reactor to the point of criticality and to heating power. The fully withdrawn control rods are distributed in a checker board (black and white) pattern. The remaining rods are sequentially withdrawn to either full out or intermediate positions in the order specified by the sequence.

Notch Error

All rods in groups higher than that in which the black and white pattern is achieved have notch control restraints superimposed on the normal group limits. This means that in addition to remaining within the group limits, any rod contained in one of these notch control groups must remain within one notch position of every other rod in the group.

A notch error occurs whenever the reactor is operating in a rod group higher than that in which a black and white pattern is achieved and notch limits are violated (rods in a group are more than one notch apart).

Low Power Set Point

The low power setpoint is the core average power level below which the Rod Worth Minimizer program is active in forcing adherence to the operating sequence of rod withdrawals or insertions. When core power is above the low power setpoint, the program does not impose any rod blocks as a result of rod movement by the operator. The low power setpoint is set above the level of required enforcement (20% power) and is sensed by total steam flow as sensed by the feedwater level control system being greater than 30% of rated power.

Withdraw Error

A withdraw error can occur either when a rod contained in the current group or any lower group is withdrawn past the withdraw limit for the group, or if a rod contained in a group higher than the current group is withdrawn past the insert limit for the higher group.

Insert Error

An insert error occurs when a rod contained in the current group is inserted past the insert limit for this group, or if a rod contained in a group lower than the current group is inserted past the withdraw limit for the lower group.

Select Error

A select error occurs whenever the operator selects a rod other than one contained in the current rod group. The select error provides the operator with a warning that he has selected a rod, which if moved, will create an insert or withdrawal error.

Operation

Control rods are withdrawn according to the operating sequence. The Rod Worth Minimizer sequence restraints require that the rod groups be pulled in sequential order to specific group limits. The control rods within a group may be pulled in any order. Some flexibility is permitted by allowing two insert errors before rod blocks are applied. One withdraw error will cause a withdraw block. The rod blocks are normally applied so that only rod movements to correct errors are allowed. This forces the operator to make the necessary corrections before permitting further rod movement. Once the black and white pattern has been obtained, notch limits must be observed in addition to group limits. The rods within the group must remain within one notch position of every other rod in the group. A notch error exists if notch limits are violated resulting in rod blocks being applied forcing the correction of the notch error before rod movement can continue.

6.6.3 BWR/3 Product Line

The BWR/3 product line utilizes the same systems as the BWR/2 product line plus one additional system, Rod Block Monitoring System for power operation greater than 30% power. The Rod Block Monitoring System prevents the operator from exceeding thermal hydraulic limits in a local region of the core for a single rod withdrawal error from a limiting control rod pattern. A limiting control rod pattern is defined as a pattern which results in the core being on a thermal hydraulic limit.

6.6.3.1 Rod Block Monitoring System

The Rod Block Monitor (RBM) system is designed to prevent local fuel damage by generating a rod withdraw block under the worst permitted LPRM detector bypass and failure conditions and under the worst single rod withdrawal error when starting from any permitted power and flow condition. This system prevents overpower around a control rod by blocking the withdrawal of that rod. This prevents: the local fuel bundles from approaching MCPR limits; local power from grossly exceeding the total core power limit; and local fuel damage, by supplementing the APRM trip functions.

The system monitors local power by generating a signal from the LPRMs in the four strings which surround the rod selected for movement. The RBM function, by analysis, is not required below 70 percent power. However, it is used whenever the reactor is above 30 percent as indicated on the APRM channel which is assigned as a reference to each RBM channel. The RBM setpoints are derived from the results of various transient analyses which are performed for each fuel cycle.

The system receives a “rod select” signal from the Reactor Manual Control System. It routes the LPRM outputs from the adjacent LPRM assemblies to the averaging circuit.

The system increases the gain of the averaging circuit until its output equals, or exceeds the reference APRM signal. The system then compares this signal to a flow-biased reference signal. A rod withdrawal block is generated if the averaged LPRM signal rises above the flow-biased trip reference signal.

Typically there are two RBM channels. Each channel receives inputs from specified levels (A and C; B and D) of LPRM detectors. There are three parallel trip reference levels which will be used for generating the rod block setpoints, as shown in Figure 6.6-4.

General Electric Nuclear Energy has instituted a new program identified as Average Power Range Monitor (APRM), Rod Block Monitor (RBM), and Technical Specifications Improvements. This program is called the ARTS program. The objectives of the ARTS program are to:

- Increase plant operating efficiency.
- Update thermal limits requirements and administration.
- Improve plant instrumentation responses and accuracy.
- Improve the man/machine interface involved in plant operation.

General Electric maintains that the above objectives are attained by making the following improvements:

- Implementing a power dependent minimum critical power ration (MCPR) limit similar to that used by BWR/6.
- APRM trip setpoint requirement is replaced by more meaningful limits to reduce the need for manual setpoint adjustments and to allow direct limits administration.
- Flow-biased RBM trips are replaced with power dependent trips.
- RBM inputs from LPRMs are assigned to improve the response characteristics and to produce trip percentage increases of initial signal, Figure 6.6-5 and 6.6-6.
- Rod withdrawal error analysis is performed to more accurately reflect the actual plant conditions.

With the introduction of ARTS, the APRM setpoint setdown factor is removed.

6.6.4 BWR/4 and BWR/5 Product Lines

BWR/4 and BWR/5 product lines added an additional system to the already existing systems being used to control rod movement by imposing rod block trip signals. The introduction of the BWR/4 product lines with a higher power density core required further studies in limiting rod worth. The studies indicated a new system was needed to backup the Rod Worth Minimizer because:

- The RWM had a poor reliability record.
- The RWM could fail in an unsafe manner.
- The RWM is easily bypassed.

The new system designed to be a backup to the RWM is the Rod Sequence Control System (RSCS).

6.6.4.1 Rod Sequence Control System

The Rod Sequence Control System (RSCS) restricts rod movement to minimize the individual worth of control rods to lessen the consequences of a rod drop accident. Control rod movement is restricted through the use of rod select, insert, and withdraw blocks. The RSCS is a hardwired, redundant backup system to the RWM. It is independent of the RWM in terms of inputs and outputs, but the two systems are compatible.

The RSCS operation is divided into two modes of operation, with the black and white rod pattern being the division point. At less than a black and white pattern, the sequence control mode controls rod movement from rod full-in to the black and white rod pattern by imposing select blocks. The group notch control mode controls rod movement from the black and white rod pattern to 30% power by imposing rod withdrawal and insert blocks.

Sequence Mode Selector

The Sequence Control Mode controls rod movement from rods full in to the black and white rod pattern by imposing rod select blocks. The rods are divided into two rod groups which are compatible with the Rod Worth Minimizer rod groups. From an all rods full in condition, the operator may choose either of the two groups to begin movement. Once the operator begins to withdraw the first rod in that group, the logic will not allow selection of any rods but those in the chosen group, until all rods in that group are moved to the full out position. When all rods in the second group are moved full out, the Rod Sequence Control System will move into Group Notch Control.

The sequence control logic makes decisions on the basis of inputs from the Control Rod Drive System. It provides only full in and full out position information for each control rod drive mechanism to the Rod Sequence Control System. This information is derived from redundant switches in the control rod drive mechanism position indicating probe and is not used for digital display or by the Rod Worth Minimizer.

The sequence control logic will not allow selection of out of sequence control rod for movement.

Group Notch Control Mode

The Group Notch Control Mode controls rod movement from the black and white pattern to the 30% power bypass, by imposing rod withdrawal and insert blocks. All control rods are assigned to notch control groups which are compatible with Rod Worth Minimizer rod groups.

Group notch control logic requires that all rods within a notch control group must remain within one notch. Once a rod is moved in either direction in a notch group, rod blocks are imposed on; (1) the initially moved rod to prevent movement in the opposite direction, and (2) all other rods in that group to prevent movement in the opposite direction. After the initial movement, the logic is reset whenever all rods in the notch group are again at the same position. The logic consists of a set of memory units, one for each notch group. The memory units track the relative position of the rods in each group by sensing the rod selected, direction of rod movement requested, and the occurrence of the Reactor Manual Control System timer settle function. The logic output signals are applied to the Reactor Manual Control System as withdraw or insert blocks.

Comparison to RWM

The Rod Sequence Control System restraints are designed to be compatible with those of the Rod Worth Minimizer. Several differences in philosophy between the two systems are outlined below:

The Rod Worth Minimizer is more restrictive in the sequencing of rod movements.

The Rod Worth Minimizer applies restraints only after the operator has deviated from the operating sequence. The Rod Sequence Control System restraints are applied so that the operator is not allowed to deviate.

The Rod Worth Minimizer can be entirely bypassed manually by the operator. The Rod Sequence Control System has only limited manual bypass capability.

The Rod Worth Minimizer is computer software and can be changed by a programmer. The Rod Sequence Control System is completely hardwired.

Bypass Capability

The Rod Sequence Control System is not required to limit rod worth at greater than 20% reactor power. A system bypass signal is generated at a conservative level of 30%, as measured by a pair of pressure sensors which monitor the main turbine first stage pressure.

The circuitry does allow certain bypass capability. In the Sequence Control logic, the full in or full out position for each rod can be bypassed. This is necessary for certain surveillance tests. In the Group Notch control logic, each notch group memory has a reset button which will reset the memory regardless of previous latch states.

NEDE-24011-P

In a letter of August 15, 1986, from T. A. Pickens, Chairman of the BWR Owners Group (BWROG), an Amendment 17 to General Electric Topical Report NEDE-24011-P (GESTAR II) was proposed and agreed to by the NRC. This submittal was a request to eliminate the required use of the Rod Sequence Control System (RSCS). The proposal stated better computers used by RWMs, lower peak fuel enthalpy from a rod drop accident, an existing NRC probability study demonstrating an extremely low probability for an event exceeding fuel damage criteria (10^{-12}), and RSCS elimination would reduce operational complexity (ATWS events). To date some plants, not all, have elected to eliminate RSCS.

6.6.5 BWR/6 Product Line

The BWR/6 product line controls rod movement and rod worth with the Rod Control and Information system (RC&IS). The RC&IS consists of the electronic circuitry, switches, indicators, and alarm devices necessary to achieve control rod manipulation. To prevent inadvertent operator errors, reactor core performance and control rod positions are constantly monitored by systems that either give an alarm demanding operator attention or completely block rod movement until the error has been corrected. *The RC&IS includes interlocks that inhibit control rod movement, but does not include any of the circuitry or devices used to scram the reactor.*

RC&IS is comprised of four subsystems, (Figure 6.6-7):

- Rod Interface System (RIS)
- Rod Action Control System (RACS)

- Rod Gang Drive System (RGDS)
- Rod Position Information System (RPIS)

The RC&IS can be operated in either the gang drive or individual drive mode. In the gang drive mode, up to four control rods can be positioned at once. Discussion of the major components of the RC&IS are discussed in the paragraphs that follow.

6.6.5.1 Rod Interface System

The Rod Interface System (RIS) is a digital, time multiplexed, fixed program, special purpose computer comprised of an operator control module, rod display module, and auxiliary select module. Data to be displayed arrives at the RIS in the form of several multiplexed words originating in the RACS, Rod Action Drive System (RADS), and the Neutron Monitoring System. Several multiplexed words are entering every millisecond and are used to update the memory so that it is never greater than a few milliseconds old. Independently, the memory is being searched and transformed into the correct display for the operator.

6.6.5.2 Rod Action Control System

The Rod Action Control System (RACS) consists of two redundant channels. Each channel includes the rod pattern control function, rod motion inhibit logic, and the directional control valve timing functions. RADS receives requested control rod motion signals from the RIS and after checking for the correct rod pattern sequence and interlocks, generates a motion command and hydraulic control unit identity signal for RGDS.

Rod Pattern Controller

The purpose of the Rod Pattern Controller is to limit the worth of any control rod to minimize the undesirable effects resulting from a rod drop accident or rod withdrawal error. The rod pattern controller is a dual channel system designed as a safety related system to enforce procedural controls by applying rod blocks before any rod motion can produce high rod worth patterns. Rod pattern controllers are hard wired and are not programmable except through the use of new electronic cards.

The rod pattern controller continuously monitors the operator’s request for rod motion, checks the request against built in criteria and, if necessary, blocks the RC&IS from carrying out the request.

Rod Gang Drive System

The Rod Gang Drive System contains an analyzer section that compares motion and hydraulic control unit identity signals from two channels of the RACS. A disagreement between the signals displayed on a fault map for operator information. If the signals agree, one signal is stored in memory while the other is sent to the transponders of the hydraulic control units as an enable signal. Transponders, one for each hydraulic control unit, contain circuits that decode the motion command signals and compare the identity address to their own. If the identity matches, the hydraulic control unit responds to the operation action code for rod movement. The transponder acknowledges the command signal by sending a signal back to another comparator in the RGDS from where is was requested and where the operation is being performed. If the identity and operation code do not agree, the operation is terminated and annunciated.

6.6.6 Summary

The Rod Control System for BWR/2 through BWR/5 product lines utilize a collection of systems to accomplish the same purposes as the Rod Control and Information System supplied with the BWR/6 product line. The collection of systems used includes the Reactor Manual Control System, Rod Worth Minimizer System, Rod Sequence Control System and the Rod Block Monitoring System.

Table 6.6-1 Fuel Enthalpy vs. Fuel Damage

Condition	Enthalpy of Fuel (cal/gm)
Cladding Perforation	170
Onset of UO_2 Centerline Melting	220
UO_2 Complete Melting	280
Instantaneous Fragmentation and Dispersal of Fuel Rods	425

Note: *Although UO_2 melting occurs if the fuel enthalpy reaches 280 cal/gm, relatively few fission products are released from the fuel cladding and the resulting pressure transient is minimal. The design limit is, therefore, based on 280 cal/gm.*

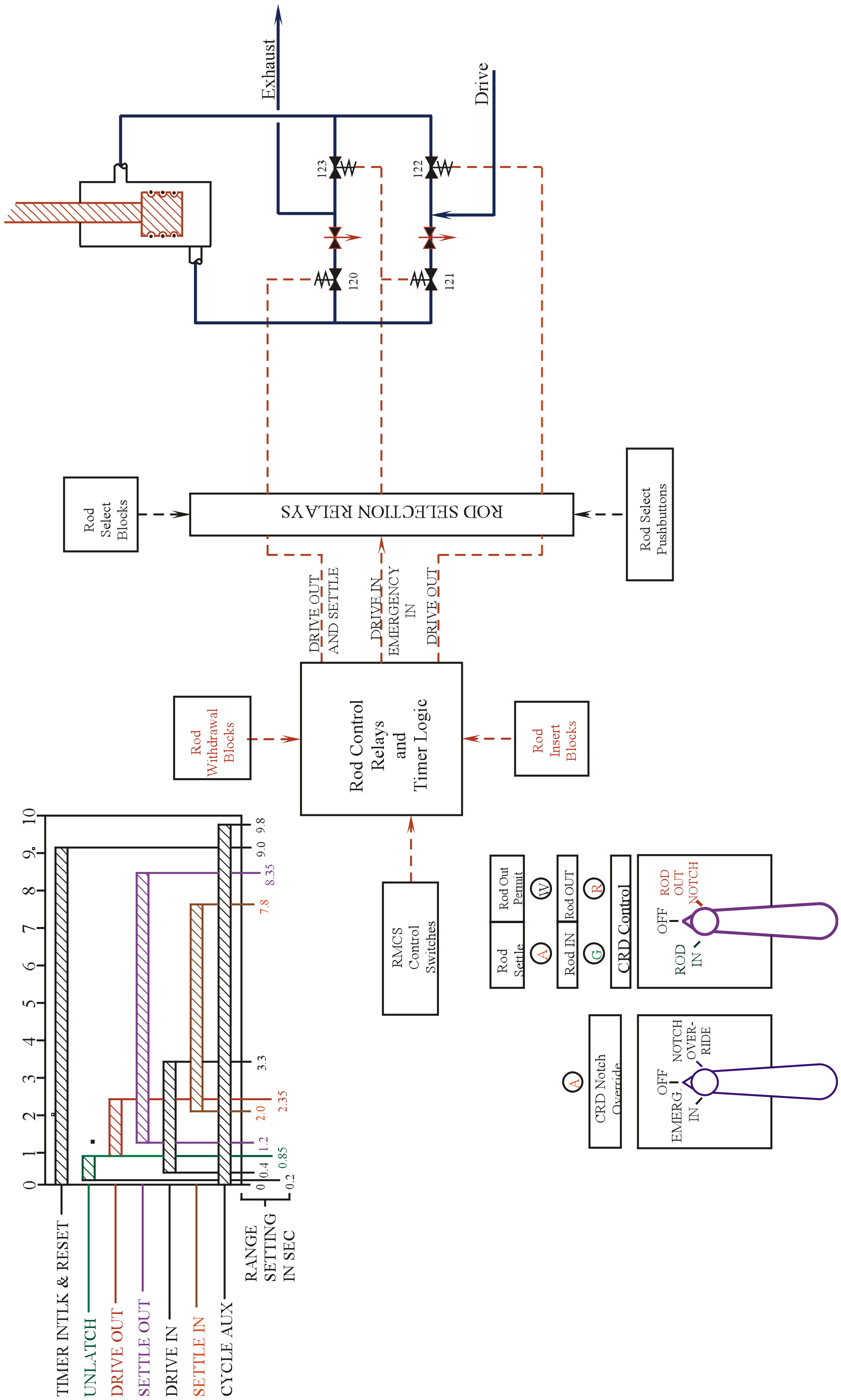

Figure 6.6-1 Reactor Manual Control System (BWR/2-5)

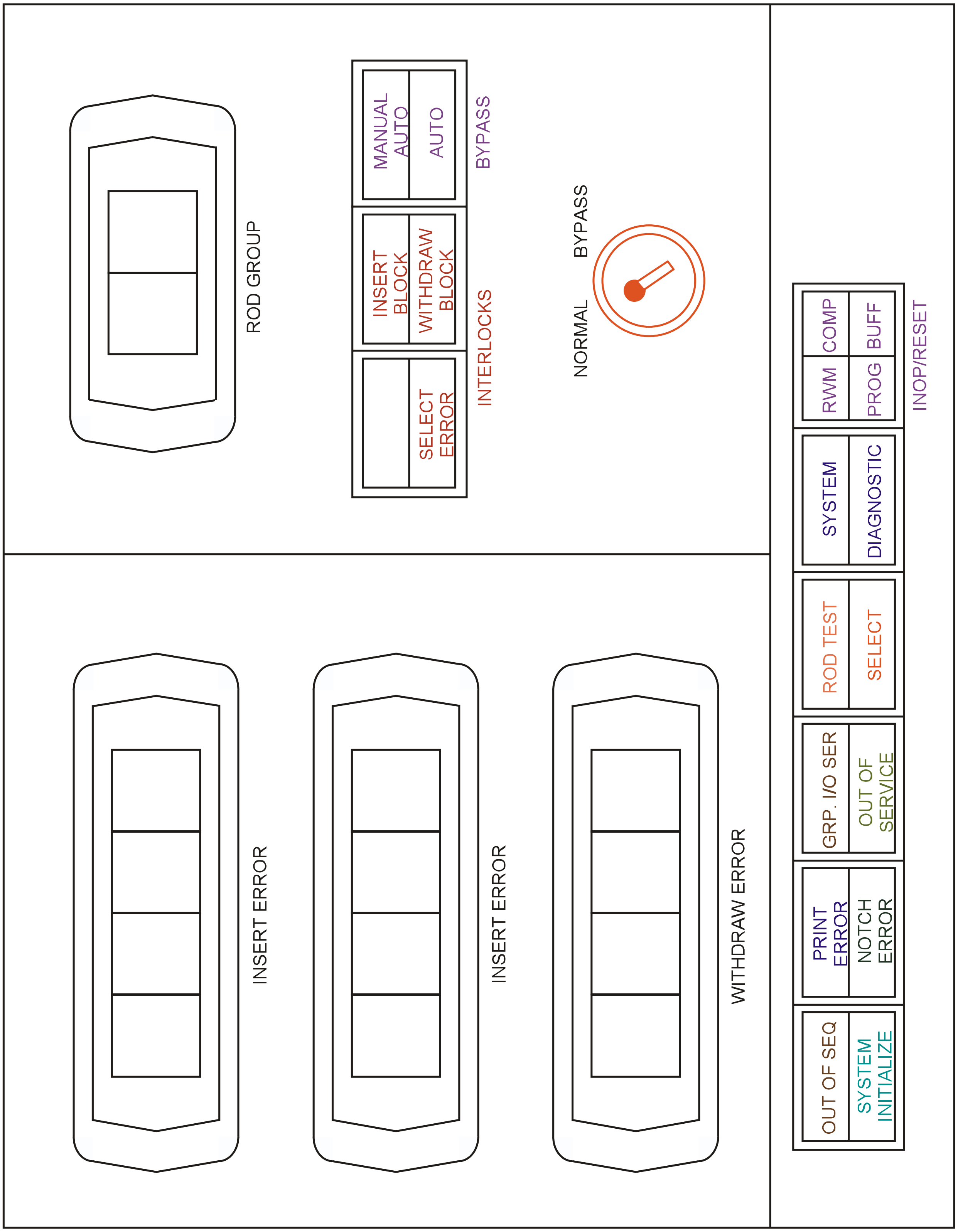

Figure 6.6-2 RWM Operator's Display Panel

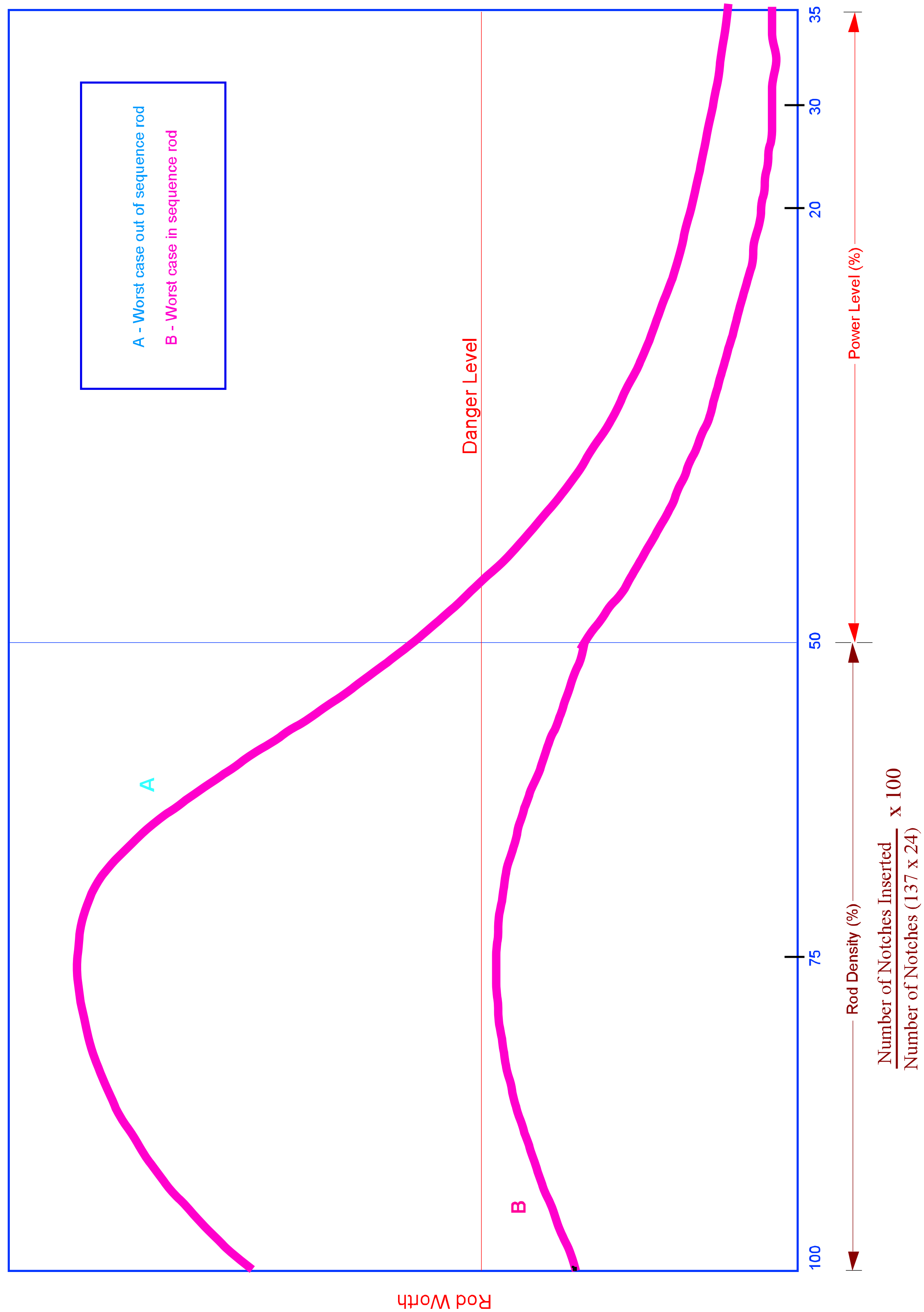

Figure 6.6-3 Rod Worth with Sequence and Notch Control Restraints

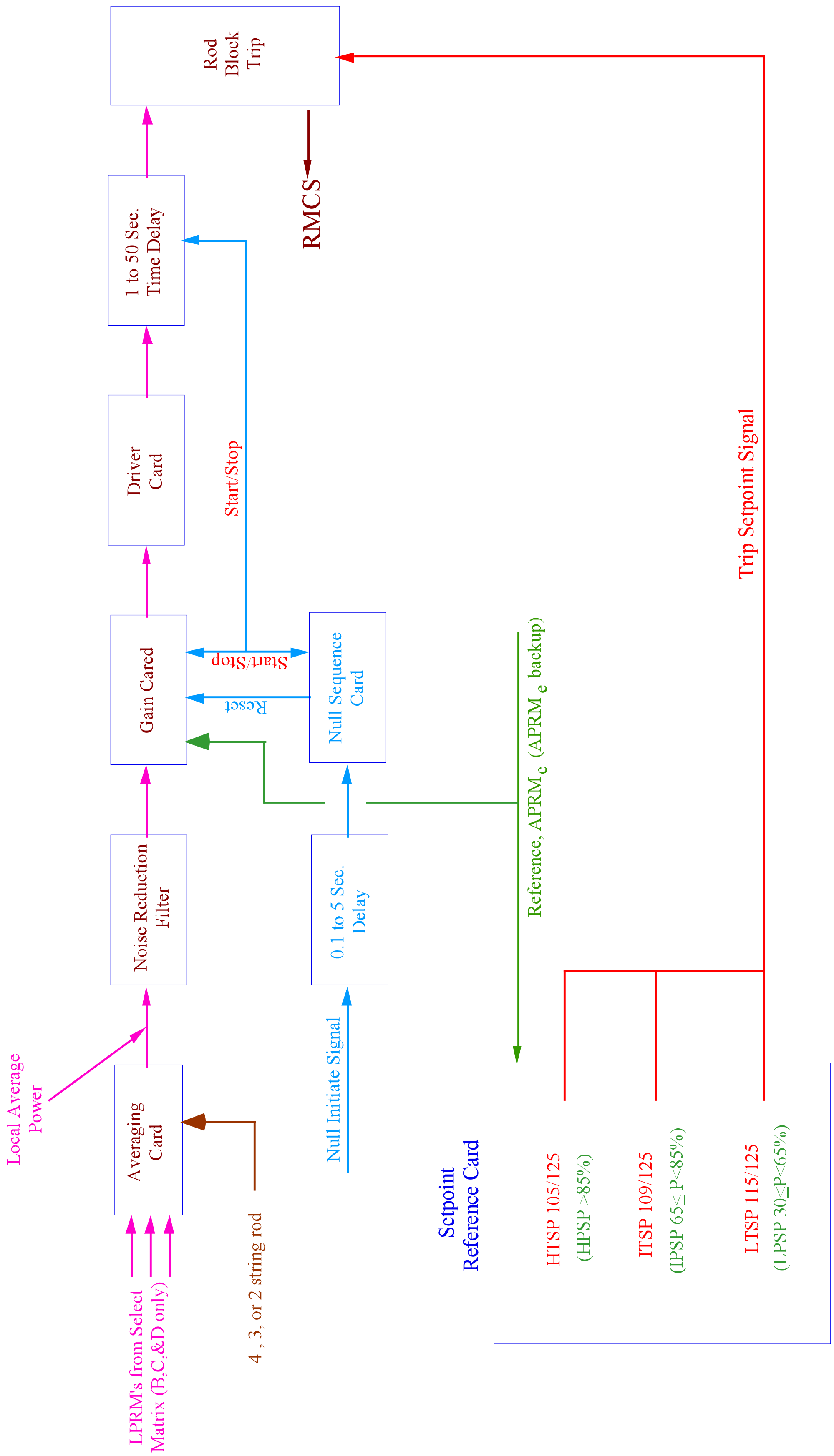

Figure 6.6-4 ARTS RBM (Channel "A")

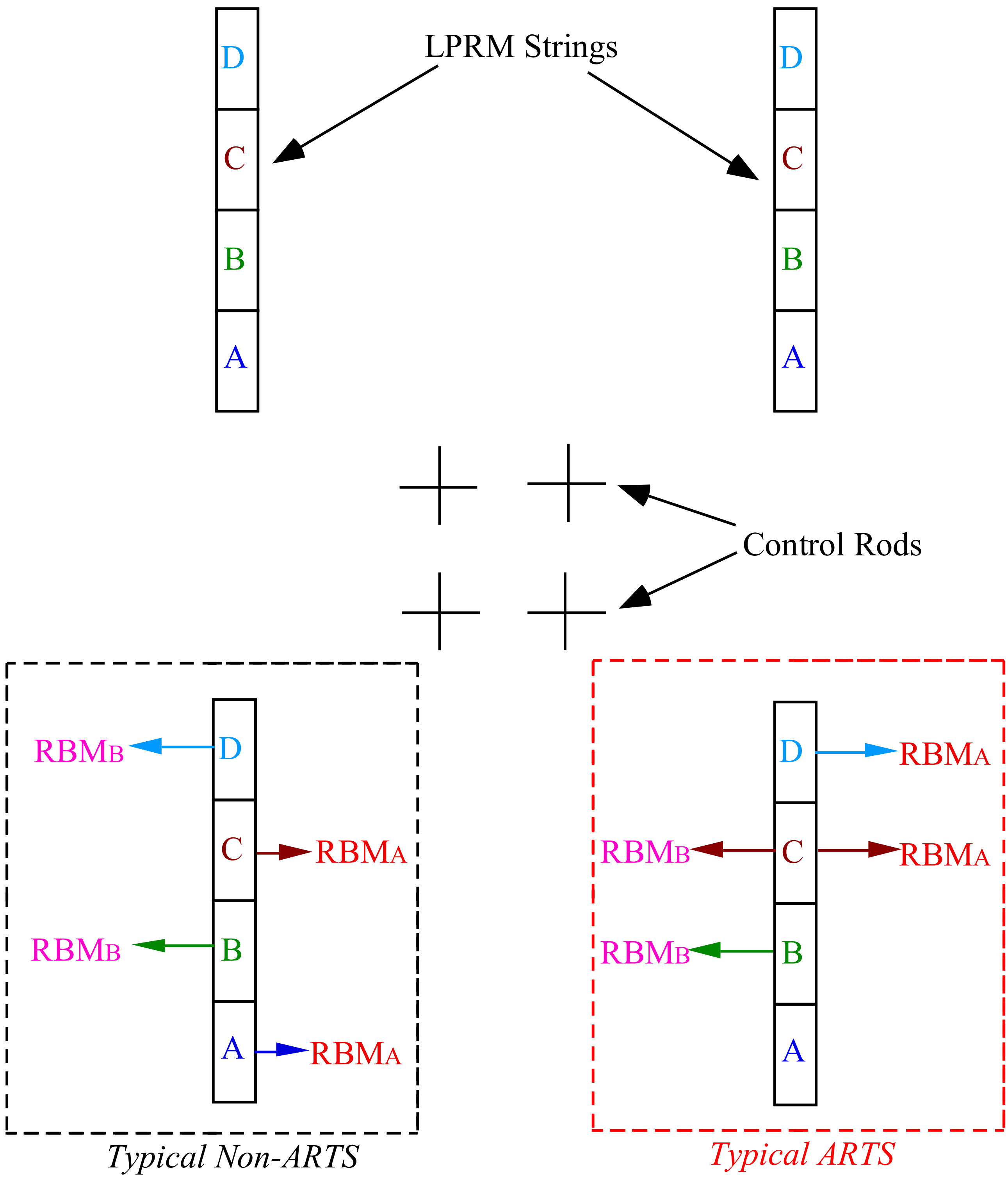

Figure 6.6-5 LPRM Assignment to RBM Averaging Ckt.

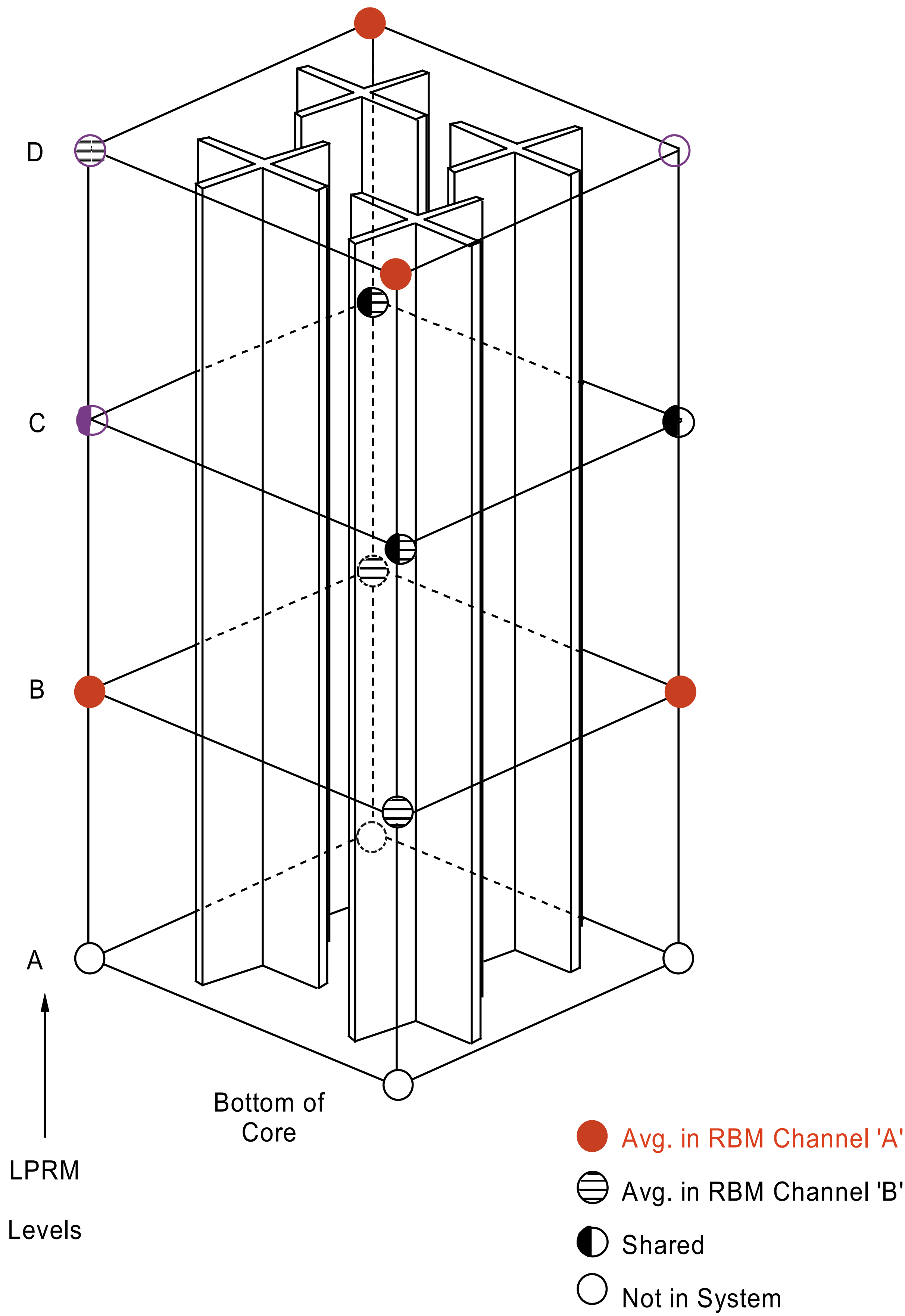

Figure 6.6-6 LPRM Assignment

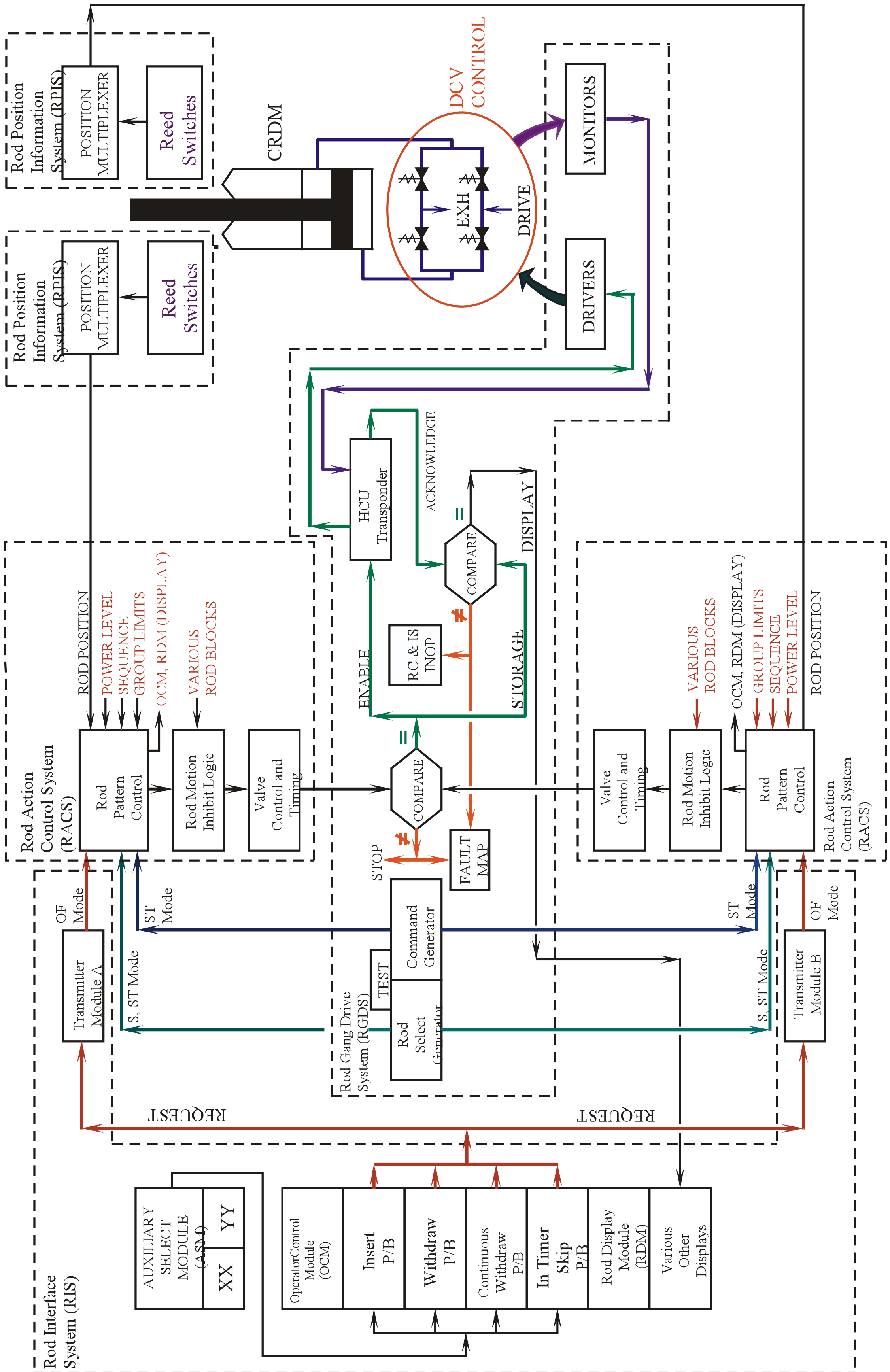

Figure 6.6-7 Rod Control & Information System